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(54) **MEASUREMENT OF VOLTAGE STANDING WAVE RATIO OF ANTENNA SYSTEM**

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CPC *G01R 27/06* (2013.01); *H04B 17/103* (2015.01); *G01R 29/10* (2013.01); *H04B 17/17* (2015.01)

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CPC G01R 23/163; G01R 27/04; G01R 31/11; G01R 35/005; H04B 3/46; H04B 3/468; E21B 43/12; E21B 49/008; E21B 49/087
USPC 343/703–908; 455/115.1–129; 324/600–699; 702/65
See application file for complete search history.

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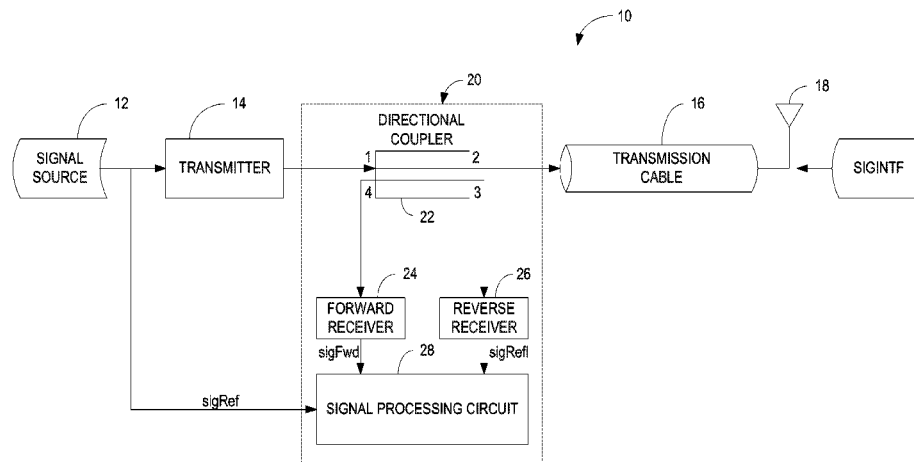*Assistant Examiner* — Lisa Peters
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(57) **ABSTRACT**

The present invention provides methods and apparatus to detect the presence of interferers in a wideband digital VSWR measurement signal. Interferers cause power differences over different intervals of time and frequency, and may be detected by comparing the measured signals in both time and frequency domains with the original signal. Frequency components in the measured signals may be discarded if the interference is deemed too large. The remaining frequency components can then be used to compute the VSWR.
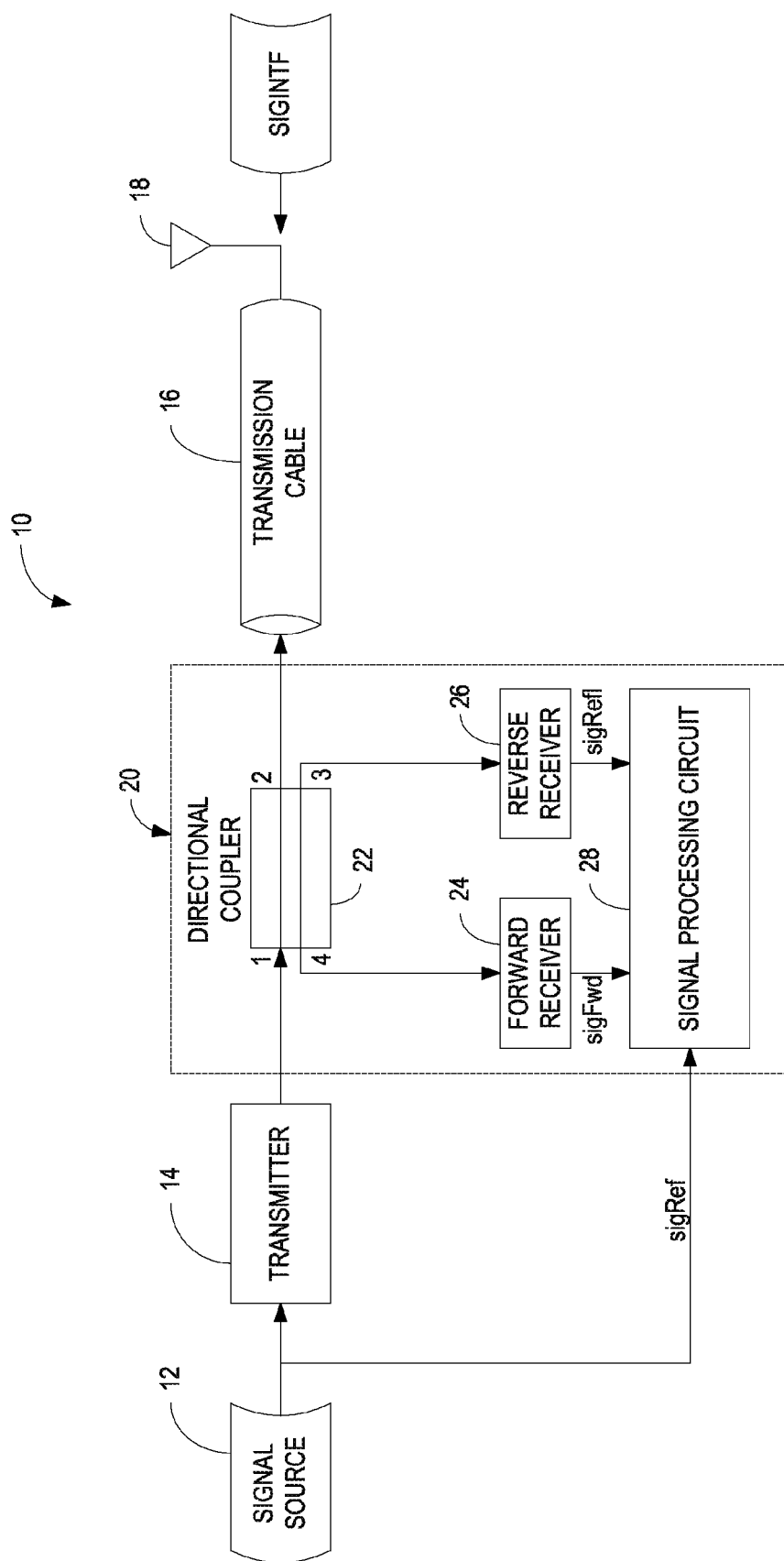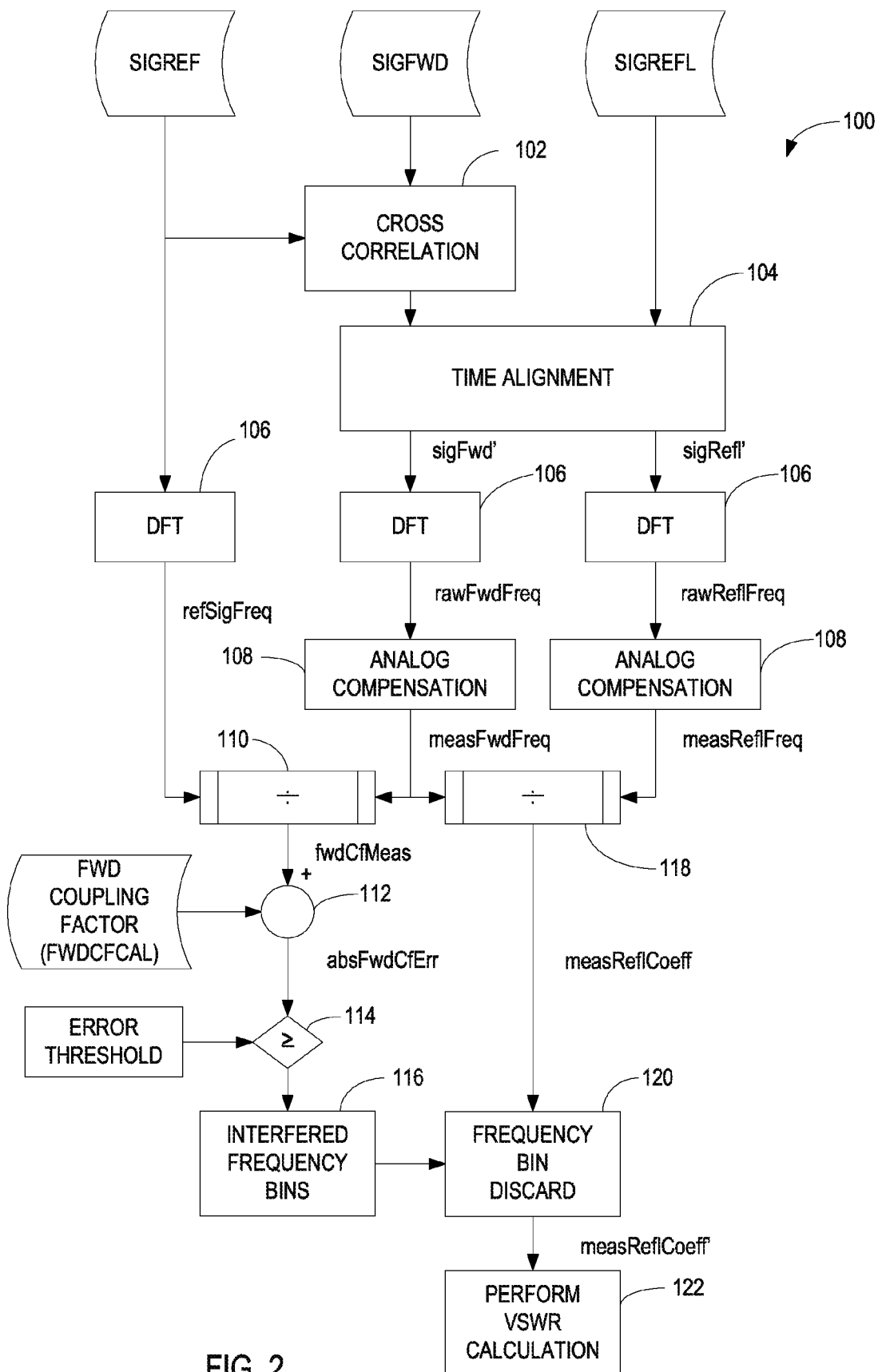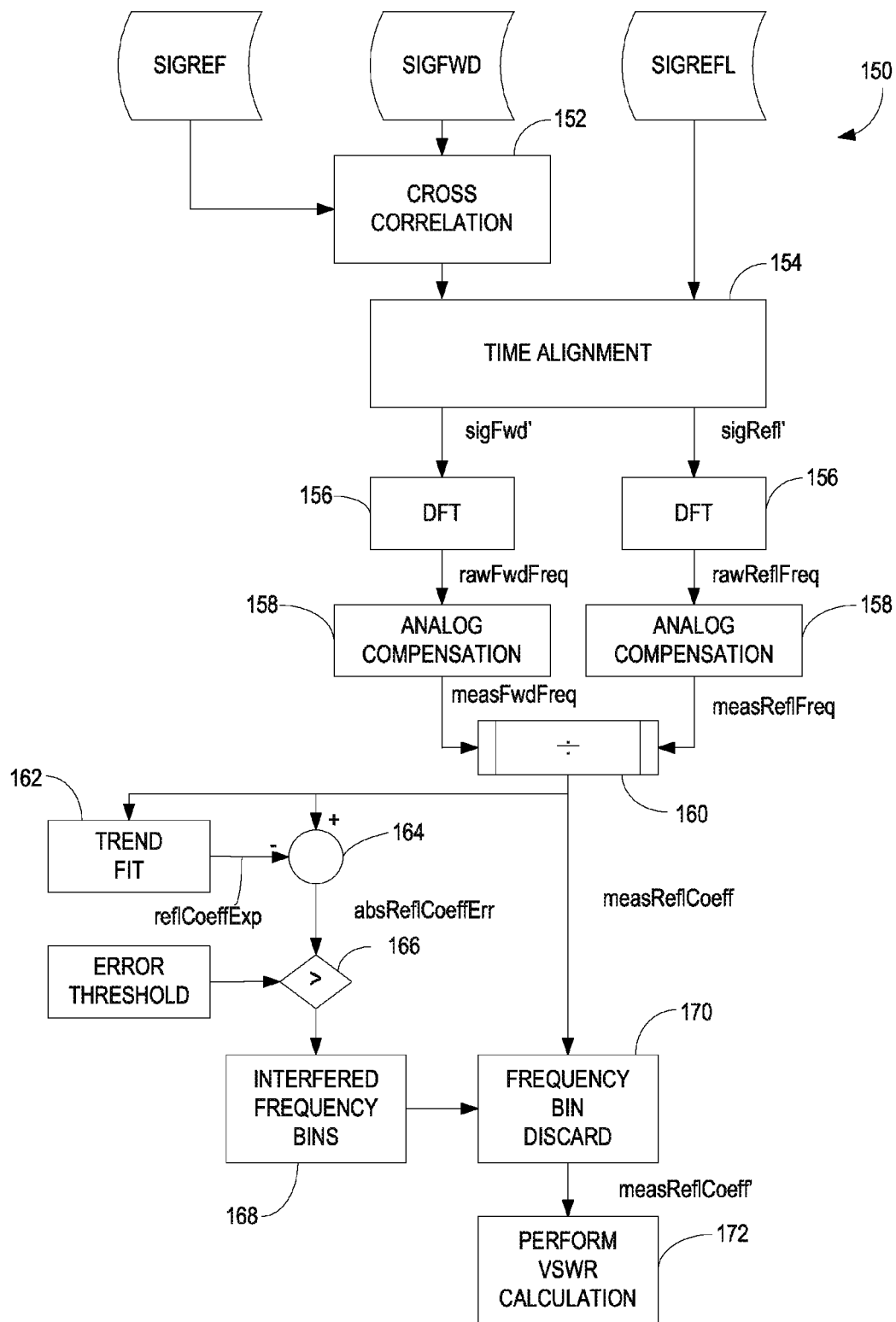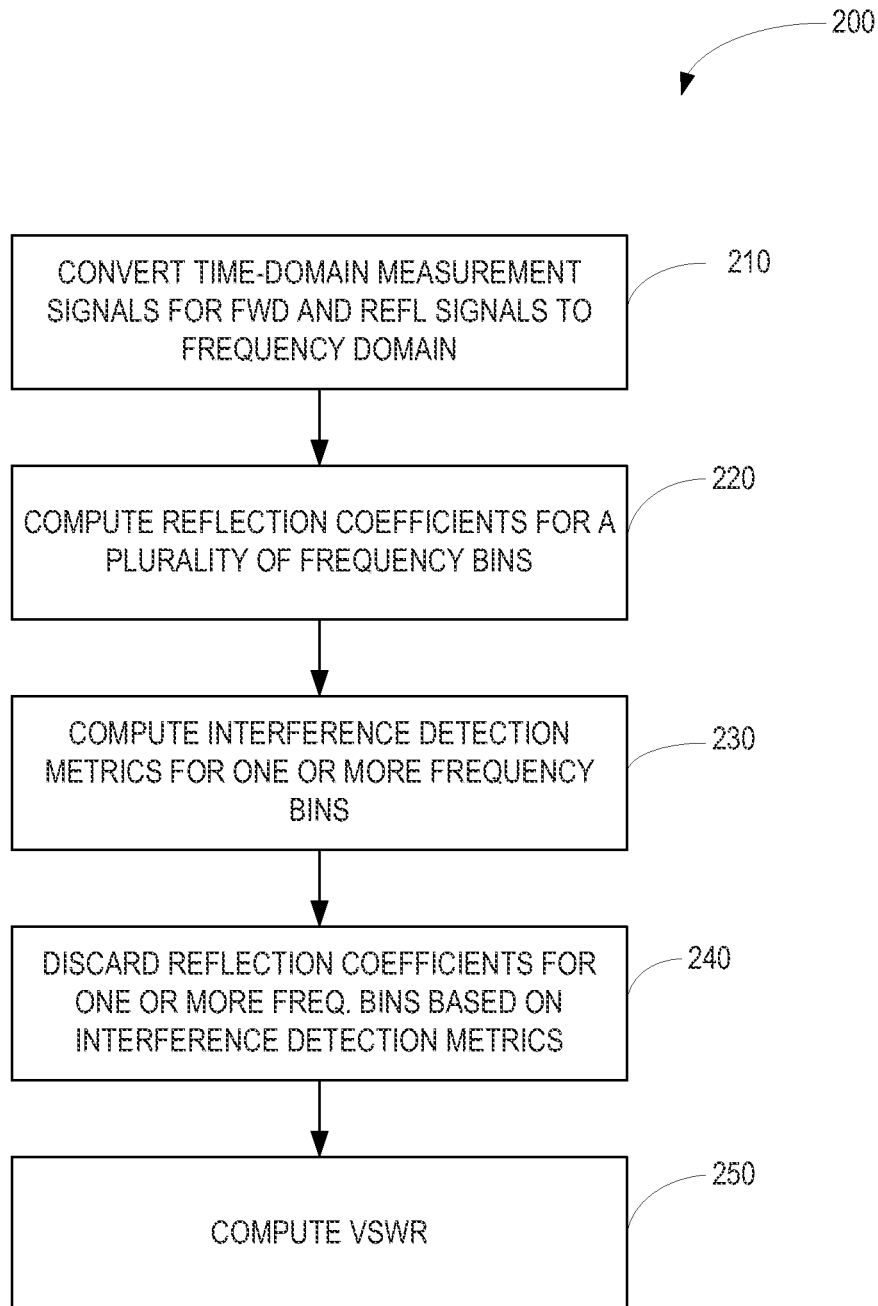
20 Claims, 5 Drawing Sheets

FIG. 1

FIG. 2

FIG. 3

200

CONVERT TIME-DOMAIN MEASUREMENT SIGNALS FOR FWD AND REFL SIGNALS TO FREQUENCY DOMAIN — 210

COMPUTE REFLECTION COEFFICIENTS FOR A PLURALITY OF FREQUENCY BINS — 220

COMPUTE INTERFERENCE DETECTION METRICS FOR ONE OR MORE FREQUENCY BINS — 230

DISCARD REFLECTION COEFFICIENTS FOR ONE OR MORE FREQ. BINS BASED ON INTERFERENCE DETECTION METRICS — 240

COMPUTE VSWR — 250

Fig. 4

FWDCFMEAS IN SIMULATED RADIO
VSWR MEASUREMENT SYSTEM

FIG. 5

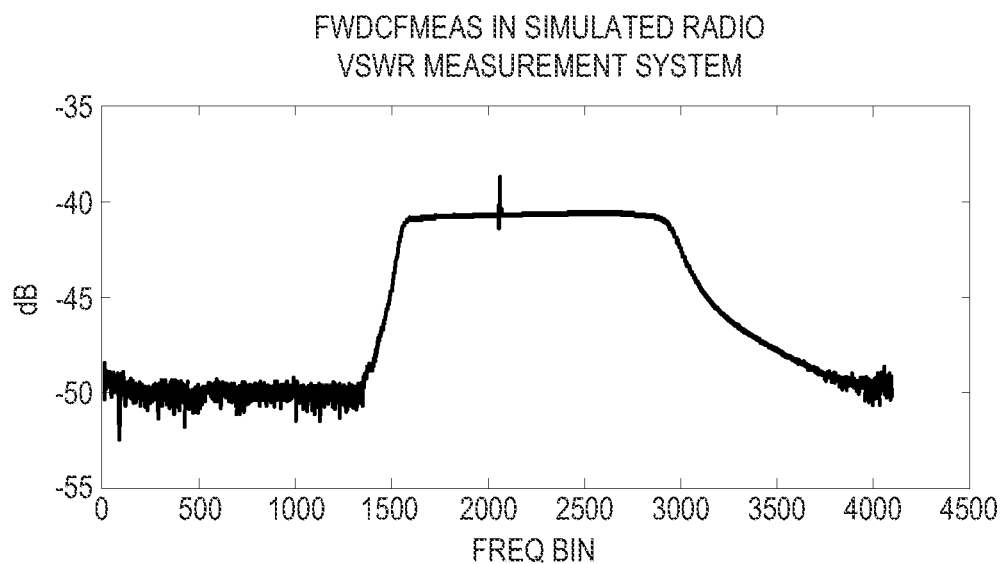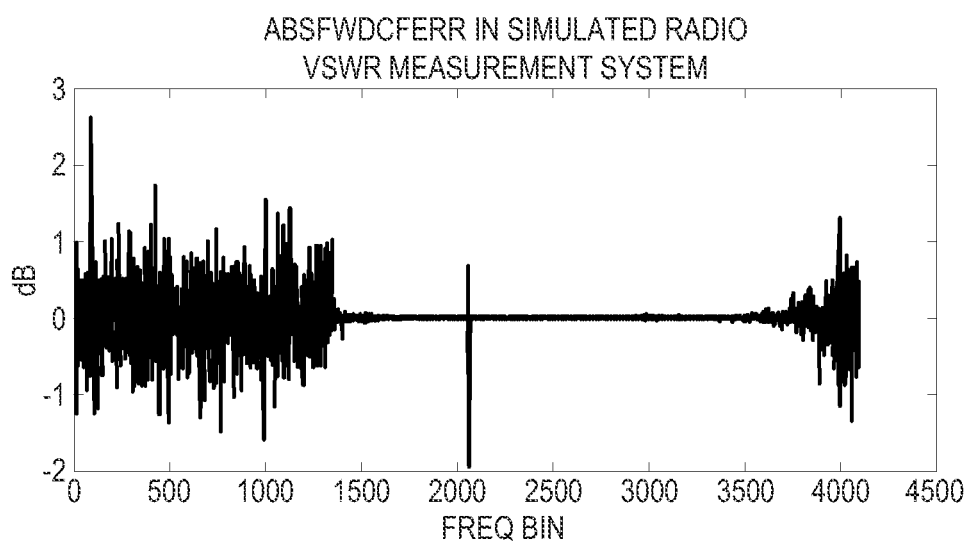ABSFWDCFERR IN SIMULATED RADIO
VSWR MEASUREMENT SYSTEM

FIG. 6

MEASUREMENT OF VOLTAGE STANDING WAVE RATIO OF ANTENNA SYSTEM

TECHNICAL FIELD

The present invention relates generally to measurement of the Voltage Standing Wave Ratio (VSWR) of antenna systems and, more particularly, to measurement techniques to reduce the impact of interfering signals in the calculation of the VSWR.

BACKGROUND

Traditionally, the Voltage Standing Wave Ratio (VSWR) of antenna systems is measured using filtered or narrow-band power measurements. By measuring the power of the forward and reflected signals (P_{fwd} and P_{refl}) simultaneously, the scalar return loss (RL) and reflection co-efficient (Γ) can be calculated.

Typical VSWR measurement systems consist of a directional coupler, and analog power detectors to measure the voltage of the forward signal, denoted V_{fwd}, and the voltage of the reflected signal, dentoed V_{refl}. A mixer circuit and low pass filter are used to measure the VSWR over a specific frequency and bandwidth. An analog to digital converter (ADC) quantizes the power detector value. High values of V_{refl} relative to V_{fwd} indicate potential transmission line and antenna faults. Both V_{refl} and V_{fwd} will be affected if there is an interference signal coupled into the measurement within or even adjacent to the measurement bandwidth.

The current analog VSWR (AVSWR) and narrowband digital VSWR (DVSWR) measurement systems are unable to detect or account for interferers as they have no knowledge of the dynamic interferer. False alarms can be raised if the interference is large enough to raise the V_{refl} such that it looks like a cable fault. False alarms may cause outages in the network if the transmission signal is turned off by fault management software to prevent damage to the radio in the event of a cable fault. False alarms also may cause unnecessary maintenance on the radio and antenna system. Therefore, special tests are used to verify the sensitivity of the AVSWR measurement to adjacent interferers.

Another drawback is that the AVSWR measurement can only be performed over a small bandwidth determined by the configured frequency of the mixer and low pass filter. The AVSWR method cannot measure the V_{fwd} or V_{refl} separately. Any voltage induced on the antenna system due to an interferer will be coupled into both the V_{fwd} and V_{refl} signals, and will impact the accuracy of the measurement. The level of coupling is based on the S-parameters of the directional coupler.

The AVSWR measurement method also does not compare the V_{fwd} or V_{refl} with the original transmitted signal, denoted V_{ref}, and thus does not determine if there is any interference that impacts the overall accuracy of the measurement.

SUMMARY

The present invention provides methods and apparatus to detect the presence of interferers in a wideband digital VSWR measurement signal. Interferers cause power differences over different intervals of time and frequency, and may be detected by comparing the measured signals in both time and frequency domains with the original signal. Frequency components in the measured signals may be dis-

carded if the interference is deemed too large. The remaining frequency components can then be used to compute the VSWR.

Exemplary embodiments of the invention comprise methods of measuring the VSWR in a wideband communication system. In one exemplary embodiment, time-domain measurement signals for a forward wave and a reflected wave are converted to a frequency domain. Reflection coefficients are then computed for a plurality of frequency components in the measurement signals. The reflection coefficients are used to compute interference detection metrics for one or more of said frequency components in the measurement signals. Frequency components in the forward wave, the reflected wave, or both, may be discarded based on the interference detection metrics, and the the remaining frequency components in the forward and reflected waves are used to compute the VSWR.

Other embodiments of the invention comprise a wireless terminal configured to compute a VSWR. The wireless terminal comprises a directional coupler connected between a transmitter and an antenna, a receiver circuit to generate time domain measurement signals for forward and reflected waves, and a processing circuit for computing the VSWR. The processing circuit is configured to convert time-domain measurement signals for the forward wave and the reflected wave to a frequency domain; compute reflection coefficients for a plurality of frequency components in the measurement signals as a function of the reflection coefficients, compute interference detection metrics for one or more of said frequency components in the measurement signals, discard one or more frequency components in the forward wave or the reflected wave, or both, based on the interference detection metrics, and compute a VSWR for the forward wave and the reflected wave based on the remaining frequencies in the forward and reflected waves.

The present invention enables the detection of an interfering signal in measurement signals used to compute the VSWR. As a result, elements in the measurement signals containing interference may be discarded before the VSWR is computed. False alarms can be avoided, resulting in fewer service calls and network outages.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a wireless terminal including a measurement circuit for measuring the voltage standing wave ratio (VSWR) of the antenna system.

FIG. 2 illustrates exemplary processing for computing the VSWR according to one exemplary embodiment.

FIG. 3 illustrates exemplary processing for computing the VSWR according to a second exemplary embodiment.

FIG. 4 illustrates an exemplary method of computing a VSWR for an antenna system.

FIG. 5 is an exemplary graph of the measured coupling factor showing an interfering signal.

FIG. 6 is an exemplary graph of the forward coupling factor error showing an interfering signal.

DETAILED DESCRIPTION

FIG. 1 illustrates an exemplary wireless terminal 10 including a measurement circuit 20 for determining a voltage standing wave ratio (VSWR). A signal source 12 generates a digital signal for transmission over a wireless channel. The digital signal is applied to the input of a transmitter 14. After conversion to analog form, the transmitter 14 upconverts, filters, and amplifies the signal. The

US 9,482,705 B2

3

output of the transmitter **14** is coupled via a transmission cable **16** to a transmit antenna **18**. A measurement circuit **20** is coupled to the transmission cable **18** between the transmitter **14** and antenna **18** to measure the voltage standing wave ratio (VSWR) of the antenna system. As will be hereinafter described in greater detail, the measurement circuit **20** is configured to detect interferers in the signals on which measurements are made, and to remove frequency components of the measurement signals containing excessive interference.

The measurement circuit **20** includes a directional coupler **22**, forward receiver **24**, a reverse receiver **26**, and a signal processing circuit **28**. The directional coupler **22** generates scaled versions of the transmitted signal, i.e the forward signal, and reflected signal. An interfering signal may be coupled by the directional coupler **22** into both the forward and reflected signals. The forward receiver **24** receives the scaled version of the transmit signal, referred to as the forward measurement signal (sigFwd). The forward receiver **24** demodulates and digitizes the forward measurement signal. The reverse receiver **26** receives a scaled version of the reflected signal, referred to as the reflected measurement signal (sigRefl). The reverse receiver **26** demodulates and digitizes the reflected measurement signal. The digitized measurement signals are input to the signal processing circuit **28**. Additionally, the original signal is applied to the signal processing circuit **28** and used as a reference signal (sigRef).

The signal processing circuit **28** has two main functions. First, the signal processing circuit **28** detects the presence of interfering signals within or adjacent to the measurement bandwidth. As described in greater detail below, interfering signals may be detected by comparing the measurement signals with the original transmitted or reference signal in both the time and frequency domain. Second, the signal processing circuit **28** calculates the VSWR of the antenna system based on the measurement signals. For purposes of calculating the VSWR, frequency components in the measurement signals corrupted by interference are discarded.

FIG. **2** illustrates exemplary processing steps **100** performed by the signal processing circuit **28** in one embodiment. The inputs to the signal processing circuit **28** include sigRef, sigFwd, and sigRefL. The signals sigRef, sigFwd, and sigRefL are sampled over a finite period of time. The measurement signals sigFwd and sigRefL may be sampled as RF signals and converted to the digital domain. The reference signal (sigRef) may comprise a baseband signal, or may be sampled as an analog RF signal in a manner similar to sigFwd and sigRefL.

The signal processing circuit **28** cross correlates sigFwd with sigRef to find the peak correlation and determine the sample offset (block **102**). Once the sample offset is known, the signal processing circuit **28** time-aligns sigFwd and sigRefL with sigRef (block **104**). The signal processing circuit **28** then performs a Discrete Fourier Transform (DFT) or other transform operation to convert the time-aligned signals (sigRef, sigFwd', sigRefl') from the time domain to the frequency domain (block **106**). The frequency domain signals (refSigFreq, rawFwdFreq, and rawReflFreq) represent the magnitude and the phase of the signals with respect to frequency. The signal processing circuit **28** compensates rawFwdFreq and rawReflFreq for nonlinearities in the analog circuits by applying calibration factors determined during radio calibration procedures (block **108**). The signals output from the analog compensation function are the measured forward frequency (measFwdFreq) and measured reflected frequency (measReflFreq).

4

The signal processing circuit **28** calculates a measured forward coupling factor, (fwdCfMeas) for each of a plurality of frequency bins (block **110**). The forward coupling factor for a given frequency bin is equal to the measured forward frequency divided by the reference signal frequency (measFwdFreq/refSigFreq). FIG. **5** shows a graph of the forward coupling factor for a white noise reference signal with a GSM interferer. The measured forward coupling factor (fwdCfMeas) is compared against the known coupling factor (fwdCfCal) determined at the time of calibration. The difference between the measured forward coupling factor and the calibrated coupling factor is computed to obtain an absolute forward coupling factor error (absFwdCfErr) (block **112**). FIG. **6** shows a graph of the forward coupling factor error for a white noise reference signal with a GSM interferer.

The forward coupling factor error is used as an interference detection metric. A high forward coupling factor error indicates the presence of an interfering signal. Therefore, the forward coupling factor error computed for each frequency bin can be compared to an error threshold (block **114**). If the forward coupling factor error is greater than or equal to the error threshold, it is determined that interference is present in the corresponding frequency bin (block **116**).

The signal processing circuit **28** also computes a measured reflection coefficient (measReflCoeff) for each frequency bin. The measured reflection coefficient is computed by dividing the measured forward frequency by the measured reflected frequency (measFwdFreq/measReflFreq). The measured reflection coefficients for frequency bins where interference is present are then discarded (block **120**). The measured reflection coefficient for the remaining frequency bins are used to compute the VSWR (block **122**). The VSWR is given by:

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1+\rho}{1-\rho}$$

where $\rho=|\Gamma|$ and Γ is the measured reflection coefficient.

FIG. **3** illustrates exemplary processing steps **150** performed by the signal processing circuit **28** in another exemplary embodiment. In this embodiment, the measured reflection coefficient is compared to an expected reflection coefficient to detect the presence of interfering signals in the measurement signals. The frequency components containing interference are discarded and the VSWR is calculated based on the remaining frequency components.

The signal processing circuit **28** cross-correlates the forward signal with the reference signal to determine a sample offset (block **152**). The sample offset determined by the cross-correlation is used to time align the forward signal and reflected signal (block **154**). The time-aligned signals (sigFwd', sigRefl') are then converted from the time domain to the frequency domain by a DFT operation (block **156**). Analog compensation is applied to the raw frequency domain signals (rawFwdFreq and rawReflFreq) as previously described to obtain a measured forward frequency (measFwdFreq) and measured reflected frequency (measReflFreq)(block **158**).

A measured reflection coefficient (measReflCoeff) is computed by dividing the measured forward frequency by the measured reflected frequency (block **160**). The measured reflected coefficient is input to a trend-fitting algorithm to obtain an expected reflection coefficient (reflCoeffExp) (block **162**). The signal processing circuit **28** determines a

5

6

difference between the measured reflected coefficient and the expected reflected coefficient (block 164). This difference represents the absolute reflection coefficient error (absReflCoeffErr). Because interfering signals will result in a detectable error in the reflection coefficient over the bandwidth of the measured signals, the reflection coefficient error can be used as an interference detection metric.

The reflection coefficient error is compared to an error threshold (block 166). If the reflection coefficient error exceeds the error threshold, it is determined that the corresponding frequency component contains an interfering signal (block 168). The frequency components containing the interfering signals are discarded (block 170). The measured reflection coefficients for the remaining frequency components are used to compute the VSWR as previously described (block 172).

FIG. 4 illustrates a general method 200 performed by the signal processing circuit 28 to compute the VSWR. The signal processing circuit 28 converts time domain and measurement signals to the frequency domain (block 210). As previously noted, the frequency domain representation represents the magnitude and phase as a function of frequency. The bandwidth is divided into a plurality of frequency bins. The signal processing circuit 28 computes reflection coefficients for each of the frequency bins (block 220). The signal processing circuit 28 also computes an interference detection metric for each frequency bin (block 230). In the embodiment shown in FIG. 2, the interference detection metric comprises the forward coupling factor error. In the embodiment shown in FIG. 3, the interference detection metric comprises the reflection coefficient error. Based on the interference detection metric, the signal processing circuit 28 discards frequency components in the measurement signals corresponding to frequency bins where the interfering signal is detected (block 240). The VSWR is then computed based on the remaining frequency components (block 250).

The techniques described herein enable the detection of an interfering signal in measurement signals used to compute the VSWR. As a result, frequency components in the measurement signals containing interference may be discarded. False alarms can be avoided, resulting in fewer service calls and network outages. Thus, network operators would see a significant savings. In cases where the interfering signal is persistent, the interfering signal can be identified and an appropriate response can be sent to the operator (alarms, warnings, or other corrective action).

Thus, the foregoing description and the accompanying drawings represent non-limiting examples of the methods and apparatus taught herein. As such, the present invention is not limited by the foregoing description and accompanying drawings. Instead, the present invention is limited only by the following claims and their legal equivalents.

What is claimed is:

1. A method implemented in a wireless transmitter of measuring a voltage standing wave ratio (VSWR) of an antenna system, said method comprising:
  generating time-domain measurement signals corresponding respectively to a forward signal and a reflected signal in a transmission line of the antenna system;
  converting the time-domain measurement signals to a frequency domain;
  computing reflection coefficients for a plurality of frequency bins based on said frequency-domain measurement signals;

detecting interference in one or more of said frequency bins based on the reflection coefficients;
  discarding reflection coefficients for one or more frequency bins in which interference has been detected;
  computing the VSWR based on the reflection coefficients for the remaining frequency bins; and
  controlling, based on the computed VSWR, transmission of a signal on the transmission line, wherein the controlling comprises refraining from transmitting the transmission signal on the transmission line.

2. The method of claim 1 wherein converting time-domain measurement signals for a forward signal and reflected signal to a frequency domain comprises computing discrete Fourier transforms of the measurement signals for the forward signal and the reflected signal.

3. The method of claim 1 wherein computing reflection coefficients for a plurality of frequency bins based on said reflection coefficients comprises dividing a magnitude of the measurement signal for the reflected signal by a corresponding magnitude of the measurement signal for the forward signal.

4. The method of claim 1 wherein detecting interference in one or more of said frequency bins based on the reflection coefficients comprises:
  computing interference detection metrics for said one or more frequency bins; and
  detecting interference in one or more frequency bins based on the interference detection metrics.

5. The method of claim 1, wherein the method further comprises using the computed VSWR to determine a potential transmission line and/or antenna fault, and the controlling comprises refraining from transmitting the transmission signal on the transmission line when it is determined there is the respective potential transmission line or antenna fault.

6. The method of claim 4 wherein detecting interference in one or more frequency bins based on the interference detection metrics comprises
  comparing the interference detection metrics for one or more frequency bins to a detection threshold.

7. The method of claim 4 wherein computing interference detection metrics for one or more of said frequency bins comprises computing measurement errors for each of the frequency bins as a function of its corresponding reflection coefficient, and wherein said measurement errors comprise the interference detection metrics.

8. The method of claim 7 wherein discarding frequency bins comprises discarding frequency bins where the measurement error satisfies an error threshold.

9. The method of claim 7 wherein computing measurement errors for each of the frequency bins as a function of its corresponding reflection coefficient comprises:
  computing a forward coupling factor for each frequency bin as a function of the measurement signal for the forward signal and a reference signal; and
  computing the measurement error as a function of the difference between the forward coupling factor and a reference value.

10. The method of claim 7 wherein computing measurement errors for each of the frequency bins as a function of its corresponding reflection coefficient comprises computing the measurement error based on a difference between the computed reflection coefficient and an expected reflection coefficient.

11. A measurement circuit for measuring a voltage standing signal ratio (VSWR) in an antenna system, said measurement circuit comprising:

7

a directional coupler connected between a transmitter and an antenna;

a receiver circuit to generate time domain measurement signals for forward and reflected signals in a transmission line of the antenna system; and

a processing circuit configured to:

convert time-domain measurement signals for a forward signal and a reflected signal to a frequency domain;

compute reflection coefficients for a plurality of frequency bins based on said frequency-domain measurement signals;

detect interference in one or more of said frequency bins based on the reflection coefficients;

discard reflection coefficients for one or more frequency bins in which interference has been detected;

compute the VSWR based on the reflection coefficients for the remaining frequency bins; and

control, based on the computed VSWR, transmission of a signal on the transmission line by sending a control signal to refrain from transmitting the transmission signal on the transmission line.

12. The measurement circuit of claim 11 wherein the processing circuit is configured to compute discrete Fourier transforms of the measurement signals for the forward signal and the reflected signal to convert the measurement signals to the frequency domain.

13. The measurement circuit of claim 11 wherein the processing circuit is configured to divide a magnitude of the measurement signal for the reflected signal by a corresponding magnitude of the measurement signal for the forward signal to compute the reflection coefficients.

14. The measurement circuit of claim 11 wherein, to detect interference in one or more frequency bins, the processing circuit is configured to:

compute interference detection metrics for said one or more frequency bins; and

8

detect the interference in one or more frequency bins based on the interference detection metrics.

15. The measurement circuit of claim 11, wherein the processing circuit is configured to use the computed VSWR to determine a potential transmission line and/or antenna fault, and the processing circuit is configured to send the control signal to refrain from transmitting the transmission signal on the transmission line when it is determined there is the respective potential transmission line or antenna fault.

16. The measurement circuit of claim 14 wherein, to detect interference in one of more of the frequency bins, the processing circuit is configured to compare the interference detection metrics for one or more frequency bins to a detection threshold.

17. The measurement circuit of claim 14 wherein the processing circuit is configured to compute measurement errors for each of the frequency bins as a function of its corresponding reflection coefficient, and wherein said measurement errors comprise the interference detection metrics.

18. The measurement circuit of claim 17 wherein the processing circuit is configured to discard reflection coefficients for the frequency bins where the corresponding measurement error satisfies an error threshold.

19. The measurement circuit of claim 17 wherein the processing circuit is further configured to:

compute a forward coupling factor for each frequency bin as a function of the measurement signal for the forward signal and a reference signal; and

compute the measurement error for a frequency bin as a function of the difference between the forward coupling factor and a reference value.

20. The measurement circuit of claim 17 wherein the processing circuit is configured to compute the measurement error for a frequency bin as a function of a difference between the computed reflection coefficient for the frequency bin and expected reflection coefficient.

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